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EJECTA IN SN 1006: THE KNOTTY ISSUE

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ABSTRACT

We present new 1988 IUE SWP observations of a faint sdOB star situated behind the remnant of the supernova of AD 1006. These spectra along with previous IUE spectra of the star taken between 1982 and 1986 provide a detailed look at the elemental composition and dynamical properties of the SN 1006 remnant. Over the six years there have been no significant changes in the absorption features associated with the remnant at 1281, 1330, or 1420 Å. While the lack of variability in these absorption lines makes it impossible to decide whether the ejecta is distributed smoothly or in knots, it is now clear that the 1281 Å feature is a blend, requiring either S II absorption redshifted at 6000 km s⁻¹ plus Si II 1260 at 5200 km s⁻¹, or else two individual Si absorbing regions.

Keywords: *supernovae - supernova remnants - interstellar medium - stars: sdOB*

I INTRODUCTION

The galactic radio source G327.6+14.6 is the probable remnant of the bright historical supernova observed in 1006 AD. This remnant appears in the radio and X-rays as a limb brightened 30' diameter shell. Optically, there are just a few thin Balmer dominated filaments along the northwest rim. The similarity of the SN 1006 remnant's morphology and optical emission to Tycho's SNR, its high galactic latitude, the supernova's reported visual brightness and time of visibility, together with a lack of a nearby OB association have strongly suggested a Type Ia origin for SN 1006. Current models for Type Ia SN involve the disruption of a white dwarf either through mass accretion in a close binary or the merge of two white dwarfs.

Strong support for both the Type Ia nature of SN 1006 and exploding carbon-deflagration white dwarf models has come from IUE observations of a faint sdOB star positioned behind the SN 1006 remnant. Low dispersion IUE spectra of this star, referred to as the S-M star (Schweizer and Middleton 1980), reveal several strong and broad absorption features which are uncharacteristic of a sdOB star (Wu et

al. 1983, Fesen et al. 1988). Specifically, there are very strong Fe II absorptions at 1610, 2370, and 2600 Å with a velocity range of ± 5000 km s⁻¹, plus broad features at 1281, 1330, and 1420 Å. The latter features have been interpreted by Wu et al. (1983) and Fesen et al. (1988) as 1260 Si II, 1255, 1259 S II, 1302 O I, and 1393, 1403 Si IV redshifted by 5000 - 6500 km s⁻¹. The presence of an expanding sphere of iron-rich ejecta interior to O, S, and Si-rich material having velocities in excess of that seen for the iron is consistent both with observations of Type Ia SNe near maximum light, and with carbon deflagration models.

If the Si, S, and O features are caused by fast-moving knots of ejecta with dimensions on the order of 10⁻² pc, such as is observed in other young remnants, then noticeable changes in their absorption profiles and strengths can be expected on a time scale of about 10 years. In order to investigate possible changes in these absorption features, we obtained new 1988 SWP spectra of the S-M star. Below, we describe the observations and results and discuss the issue of knots of ejecta in SN 1006.

II OBSERVATIONS

Low-dispersion, short wavelength (SWP) IUE spectra of the S-M star were obtained on March 25 and 26, 1988. The exposure times were 400 minutes (SWP 33156) and 415 minutes (SWP 33164) respectively and were taken during very low radiation levels in US1 observing shifts. A log of all IUE SWP of the S-M star is given in Table 1. The two new low dispersion spectra were extracted from the spatially resolved line-by-line file provided by IUESIPS using either 5 or 7 lines. Standard calibrations and blemish corrections were applied. Placement of the S-M star within

Table I
IUE Observing Log - S-M Star

Image Number	Date	Exposure
SWP 16054	16 Jan 1982	360 min
SWP 19927	8 May 1983	360 min
SWP 27592	25 Jan 1986	400 min
SWP 27619	27 Jan 1986	330 min
SWP 33156	25 Mar 1988	400 min
SWP 33164	26 Mar 1988	415 min

the large aperture was done via a blind offset slew. Slight relative displacements of the star within the large aperture can result in small wavelength shifts, a not uncommon problem. Offset displacements of the S-M star of the order of $2 - 4''$ apparently occurred for these new observations since stellar absorption features at 1550 (C IV) and 1640 (He II) in these 1988 spectra showed wavelength differences of 7 and 6 Å with respect to rest wavelengths. The spectra were consequently shifted by these amounts so they could be compared and added to previous IUE spectra.

The two new spectra smoothed by a 3 point box function and then added together are shown in Figure 1 along with 1982/1983 and 1986 summed spectra. The summed spectrum from the three epochs is shown in Figure 2 with the major absorption features identified.

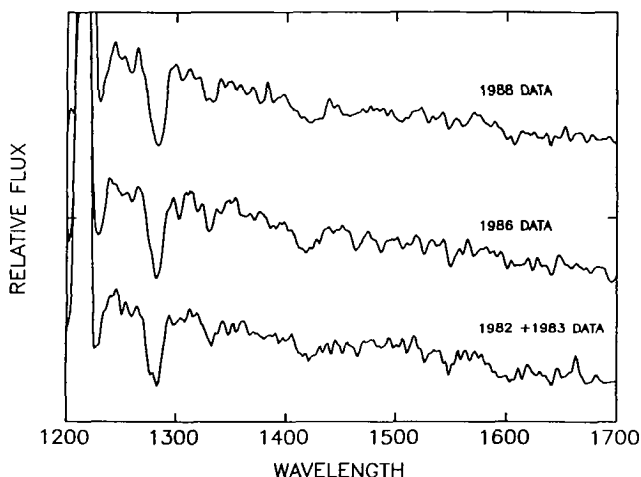


Figure 1 — Plot of summed 1982/83, 1986, and 1988 SWP spectra of the S-M star for the wavelength range 1200 to 1700 Å. Summed data as shown have been smoothed by a three point box-car function and wavelength corrected relative to the 1982 spectrum (SWP 16054).

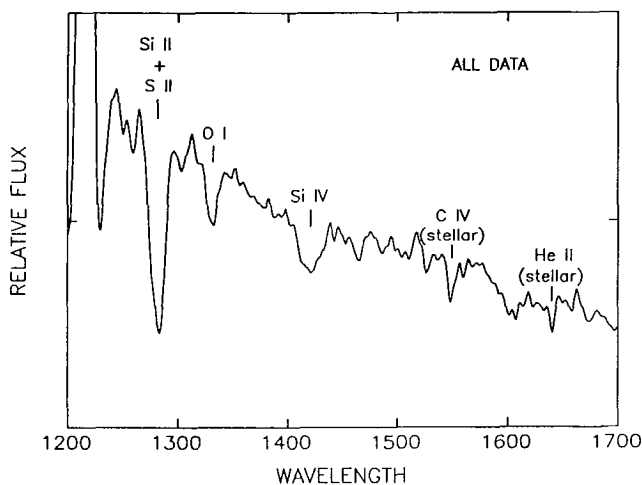


Figure 2 — Sum of all six low-dispersion SWP spectra of the S-M star for the wavelength region 1200 to 1700 Å. Probable line identifications for the stronger features are indicated.

III DISCUSSION: KNOTS OR NOT?

From the six IUE spectra taken over a period of six years, we can now better determine the reality and variability of absorption features in the S-M star. The absorption lines consistently present in the wavelength range between 1220 and 1900 Å include the features at 1260, 1281, 1330, 1420, 1527, 1550, and 1640 Å. The 1260 and 1527 Å lines appear to be conventional interstellar Si II 1260 and 1527 absorptions, while the 1550 and 1640 Å features are probably stellar C IV and He II lines, consistent with the star's sdOB classification (see Fesen et al. 1988). The possible weak stellar Fe V absorption near 1464 Å is only marginally present in the 1988 spectra. No other features in the spectrum as strong as the interstellar 1260 Å Si II line appear present.

As shown in Figure 1, the 1281, 1330, and 1420 Å features attributed to absorbing material associated with the SN 1006 have not changed substantially from 1982 to 1988. Although all six spectra are underexposed, these three lines show no equivalent width variations at the 50% level and probably at the 25% level. Possible minor changes in the 1330 Å feature mentioned by Fesen et al. are not confirmed. The only possible change observed is the 1420 Å feature which may have broadened somewhat during this time period (see Figure 1). However, none of the three absorption features show any change in their central wavelength.

As shown in Figure 3, the line identifications for these features remain essentially unchanged from those discussed by Fesen et al. The 1420 Å feature is probably the Si IV resonance lines at 1393 and 1403 Å redshifted by 5000 km s⁻¹; the 1330 Å feature can be interpreted as a blend of Si II 1304 at 5200 km s⁻¹, O I 1302 at 6500 km s⁻¹, and interstellar C II 1335; and finally, the strongest feature at 1281 Å is most likely caused mainly by the 1260 line of Si II redshifted at a velocity of 5200 km s⁻¹, i.e. close to the velocity inferred from the Si IV interpretation of the 1420 Å feature.

While the strong 1281 Å feature has not varied, the new 1988 observations in conjunction with the four previous spectra indicate that this feature is actually a blend of at least two lines; one centered near 1282 Å, and a slightly weaker one near 1277 Å. Despite the low signal to noise near the bottom of such a strong absorption feature, 5 of the 6 individual spectra suggest an unresolved blend of at least two components. The other spectrum shows a broad line profile consistent with the blended profile seen in the five other spectra. Fesen et al. (1988) concluded that while most of the 1281 feature was likely due to Si II, about 25% or so might also be redshifted S II lines (1251, 1254, 1259) at a velocity of 6000 km s⁻¹. For this feature to be a blend, either there must exist two absorbing regions of Si II along the line-of-sight, or S II absorption must be present at a more substantial intensity.

The lack of changes in these lines implies a minimum dimension of 0.06 pc (for $d = 1.7$ kpc) for the absorbing gases, but leaves open the question, discussed by Fesen et al., of whether the Si, S, and O absorbing material is unshocked ejecta, or shocked ejecta which has cooled and condensed into knots. This is an important issue for it is not yet clear whether Type Ia supernovae produce the type of clumpy ejecta seen in young supernova remnants such as Cas A

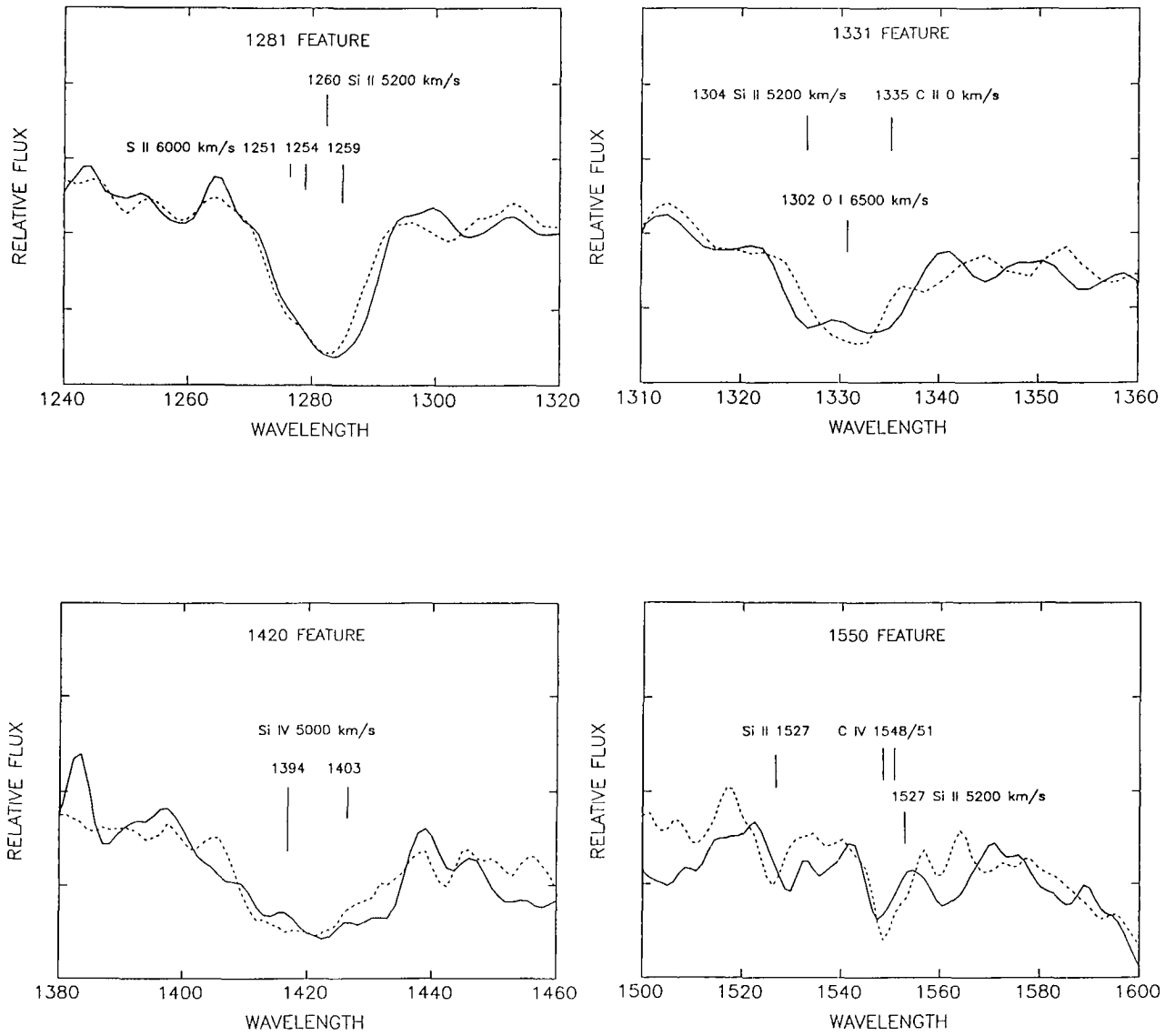


Figure 3

1988 IUE data (solid line) compared to 1982 - 1986 data (dotted line) for the strong absorption features in the spectra of the S-M star. Data shown have been wavelength shift-corrected and smoothed by a three point box-car function. Red-shifted positions of Si II, S II, O I, and Si IV are shown with relative oscillator strengths indicated by the lengths of the vertical lines. These plots are similar to Figure 8 of Fesen et al. (1988). Note the similarity of the absorption features seen in the 1988 data to that of the previous epoch data.

and the Crab Nebula. Knots in supernova ejecta may form as a result of thermal instabilities either at the time of the explosion or in reverse shocked ejecta.

The absence of variability in these lines is at least consistent with smoothly distributed unshocked ejecta. Calculations by Hamilton and Fesen (1988) indicate that any unshocked silicon should show comparable amounts of Si II and Si IV as the present time, as is observed. The Fe II absorption profiles indicate that the reverse shock lies not much beyond the 5000 km s^{-1} free expansion radius. Our identifications of absorbing material at higher velocities, namely S II at 6000 km s^{-1} and O I at 6500 km s^{-1} , are uncertain because of possible blending; for example, the 1330 O I feature might instead be Si II 1304 at 5200 km s^{-1} and interstellar C II 1335 (see Wu et al. 1983). If the S II and O I line identifications are incorrect, then it is possible that no absorbing material has yet reached the reverse shock.

On the other hand, if the absorbing regions are composed of material shocked by the blast wave's reverse shock, then the combination of low ionization and high velocity requires the absorbing material to be condensed knots of ejecta. Clumpy ejecta would be consistent with the lack of any blueshifted absorption despite the symmetry of the Fe II absorption profiles. If our identifications of S II at 6000 km s^{-1} and O I at 6500 km s^{-1} are correct, then this absorbing material must lie far ahead of the unshocked iron, in the form of shocked and cooled knots. The velocity dispersion of several hundred km s^{-1} indicated by the width of the Si IV 1420 Å feature is comparable to the velocity dispersions seen in the reverse shocked metal-rich knots of Cas A.

Unshocked ejecta will produce slowly changing lines, whereas small knots of shocked ejecta should produce more rapid variations. The most decisive evidence in favor of knots would be rapid absorption line variability. However, until such changes are observed, the question of the structure and composition of this 1000 yr old Type Ia's ejecta remains uncertain.

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